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DEVELOPMENT OF ALGORITHMS FOR EFFICIENT MANAGEMENT OF FIRE RESCUE UNITS

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Розглянуто вплив основних чинників на параметри пожежі. Отримано залежності, що дають змогу визначити значення тривалості слідування пожежного автомобіля до місця виклику та площі пожежі. Обґрунтовано необхідність та розроблено алгоритм ефективного управління діями пожежно-рятувальних підрозділів. Наведено приклад та описано роботу програмного забезпечення для вибору оптимальної технології пожежогасіння

Ключові слова: пожежно-рятувальний підрозділ, маршрутизація спецтранспорту, оцінка тривалості слідування, параметри пожежі, технологія пожежогасіння, протипожежна техніка

Рассмотрено влияние основных факторов на параметры пожара. Получены зависимости, позволяющие определить значение продолжительности следования пожарного автомобиля к месту вызова и площади пожара. Обоснована необходимость и разработан алгоритм эффективного управления действиями пожарно-спасательных подразделений. Приведен пример и описана работа программного обеспечения для выбора оптимальной технологии пожаротушения

Ключевые слова: пожарно-спасательное подразделение, маршрутизация спецтранспорта, оценка продолжительности следования, параметры пожара, технология пожаротушения, противопожарная техника

1. Introduction

The activity of operational rescue service of civil protection, in particular fire rescue units, is associated with the rapid response to fires and all sorts of emergencies. Efficiency of fire and rescue service depends on competent and rapid execution of actions aimed at minimizing the damage that may be caused by environment, such as a fire. The development of fire is associated with an increase in the area of burning and the possibilities of the impact of its dangerous factors.

There are three periods in the development of fire: free development $\tau_{f.d.}$, localization τ_{loc} and the liquidation of fire τ_{liqv}. From the view of reduction of losses, caused by the fire, the key importance is reducing the time factors $\tau_{f.d.}$, τ_{loc} and τ_{liqv}. It should be noted that the duration of the free development of fire (and, as a consequence, the fire area) is mainly affected by the travel time of fire rescue units to the place of its occurrence.

The key to effective localization and elimination of fire is the quality and skilled management of the forces and facilities that arrived to the place of the call. Here it is important that the head of fire extinguishing has sufficient information about the possibilities of the development of fire to identify the optimal quantity of forces and facilities for its elimination. Therefore, during the travel time to the place of the call, operational documentation for the object (plans and fire extinguishing cards) is being analyzed. Relevant in this case is the use of computer programs, which would give the opportunity to facilitate the calculation of parameters of development and elimination of fire, as well as the optimal quantity of forces and facilities for its extinguishing.

Therefore, taking the above-mentioned into account, the actual task is to design a set of algorithms for the management of fire rescue units' activities in order to reduce the time of the free development of fire and its rapid localization and extinguishing.

2. Analysis of scientific literature and the problem statement

The issues of reducing the travel time of operational rescue units (and, consequently, decrease in the duration of free development of fire) were tackled by a number of scientists. In particular, the questions of optimizing the routes of travel are considered in the works of the Ukrainian scientists [1–3]. In the paper [4], based on the data on travel time and the routes of movement of special vehicles over four years in Northern Virginia (the USA), a model was proposed for the selection of the route for special vehicles. In the study [5], for the estimation of travel time of special vehicles, such drivers as the intensity of the traffic flow, the number of lanes in the road network and an average speed of traffic flow are all taken into account. The paper [6] considers a model for dynamic planning of traffic routes for special vehicles with regard to the time of day, and, accordingly, the intensity of traffic flow. The paper [7] reviews a simulation of the movement of special vehicles with regard to the fact that they are allowed to skip certain requirements of the standard road rules, for example, to move against the red traffic light. However, these papers do not pay enough attention to the process of the influence of certain drivers (for example, a road network infrastructure, its characteristics, parameters of traffic flow, technical means of traffic management) on the travel time toward the place of the call.

To provide a fire-extinguishing vehicle with optimal conditions for its movement, it is necessary to identify it among the other participants of the traffic by special sound and light signals. These issues are considered in the paper [8]. In some countries, the attempts to provide a fire-extinguishing vehicle with a "green wave" along the controlled intersections were carried out [9–11]. The article [12] investigates the issue of road accidents with the involvement of special vehicles while travelling to the place of the call. The risk of accidents for fire trucks was also investigated in the paper [13].

Regarding the following fire rescue units' activities, including localization and extinguishing of fire, the selection of the optimal quantity of the forces and facilities to perform these tasks, one should pay attention to the papers [14–16]. In these works the issues of optimization of technology of fire-fighting at industrial enterprises were addressed, but only after the time of arrival of the fire rescue units to the place of the call. In particular, the authors propose to use new technical means of fire extinguishing to increase the efficiency of fire-fighting, which unfortunately not all fire rescue units possess.

However, the lack of algorithms for efficient integrated management of the fire rescue units' activities from the moment of receiving the notice of a fire until returning to the depot determines the need for research in the outlined direction.

3. The purpose and objectives of the study

The aim of this work is to design algorithms for the efficient management of the activities of fire rescue units by the study of the influence of the drivers on the processes of development and extinguishing of fire.

To achieve the goal, the following tasks were solved:

– to explore the drivers of influence on the duration of free development of fire, its localization and extinguishing with the aim of reducing time factors $\tau_{f.d.}$, τ_{loc} and τ_{liqv};

– to design an algorithm for the efficient management of the activities of fire rescue units during the process of travelling to the place of the call and for selecting optimal technologies of fire extinguishing.

4. Methods of research of the drivers of influence on the periods of fire and of design of optimization algorithm for efficient management of fire rescue units' activities

Theoretical research was carried out on the basis of methods of mathematical analysis, mathematical statistics and probability theory. The accuracy of the results of theoretical research is acceptable for carrying out engineering calculations. The obtained results were processed by using the software packages STATISTICA and Microsoft Excel.

Methods of simulation modeling applied for the design of optimization algorithm for the efficient management of fire rescue units' activities, as well as the Monte Carlo method.

5. Results of research of the influence of the drivers on the periods of fire and the design of optimization algorithm for efficient management of fire rescue units' activities

Value $\tau_{f.d.}$ can be described by dependency:

$$\tau_{f.d.} = \tau_{d.d} + \tau_{fa} + \tau_{pr} + \tau_{inv} + \tau_{ds} + \tau_{tt} + \tau_{od}, \qquad (1)$$

where $\tau_{d.d}$ is the time of fire development before its detection; τ_{fa} is the time of fire announcement to operation rescue service; τ_{pr} is the time of the fire announcement processing; τ_{inv} is the time needed for the forces and facilities involvement; τ_{ds} is the time for preparation and dispatch of fire rescue units; τ_{tt} is the travel time to the place of the call; $\tau_{od.}$ – is the time of operational deployment of forces and facilities.

As already mentioned, in most cases, the duration of the free development of fire $\tau_{f.d.}$ is affected by the travel time of fire rescue units to the place of its origin. Upon the firefighters' arrival, the fire area will continue to expand up until the moment of its localization τ_{loc} (Fig. 1).

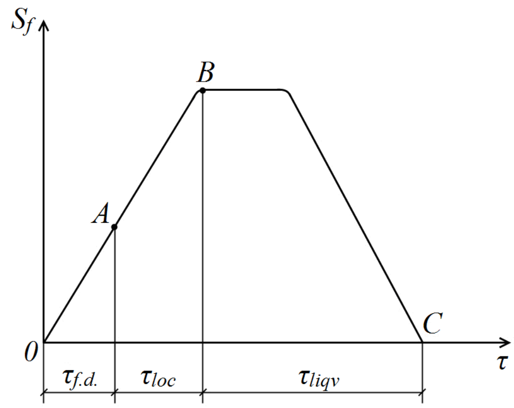

Fig. 1. Graphical dependency of fire development

In general, the value of the fire area S_f can be defined by dependency:

$$S_f = k \cdot \pi \cdot (0{,}5 \cdot V_L \cdot \tau_1 + V_L \cdot \tau_2)^2,\ m^2, \quad (2)$$

where k is the coefficient that takes into account the angle of the fire development (k=0,5 at angle 180°, k=0,25 at angle 90°); V_L is the linear velocity of a fire expansion, m/min; τ_1 is the first 10 minutes of free development of fire (const); τ_2 is the duration of free development of fire in the moment of localization, excluding τ_1.

The knowing of the value S_f by the head of fire extinguishing is extremely important, because it allows determining the required quantity of forces and facilities for its successful elimination. By using the dependency (2), one can obtain a number of dependencies that allow setting the value S_f depending on the duration of its free development. For example, for an angle fire (90°) these dependencies will have the form:

– at the linear velocity of the fire expansion V_L=0,5 m/min:

$$S_f = 0{,}1881\tau_{f.d.}{}^2 - 1{,}6859\tau_{f.d.} + 3{,}1505,\ m^2; \quad (3)$$

– at V_L=1,0 m/min:

$$S_f = 0{,}7525\tau_{f.d.}{}^2 - 6{,}7436\tau_{f.d.} + 12{,}602,\ m^2; \quad (4)$$

– at V_L=2,0 m/min:

$$S_f = 3{,}0099\tau_{f.d.}{}^2 - 26{,}975\tau_{f.d.} + 50{,}408,\ m^2; \quad (5)$$

– at V_L=3,0 m/min:

$$S_f = 6{,}7723\tau_{f.d.}{}^2 - 60{,}693\tau_{f.d.} + 113{,}42,\ m^2. \quad (6)$$

Fig. 2 [17] displays graphical dependency of area of angle (90°) fire S_f on $\tau_{f.d.}$ and V_L.

By analysing Fig. 2 and obtained dependencies (3)–(6), applying the software package STATISTICA, we obtained theoretical dependency, which allows determining the area of the fire depending on $\tau_{f.d}$ and V_L:

$$S_f = 753{,}6354 - 73{,}4825\tau_{f.d.} - \\ -876{,}5551V_L + 1{,}4038\tau_{f.d.}{}^2 + \\ +50{,}0936\tau_{f.d.}V_L + 180{,}658V_L{}^2,\ m^2. \quad (7)$$

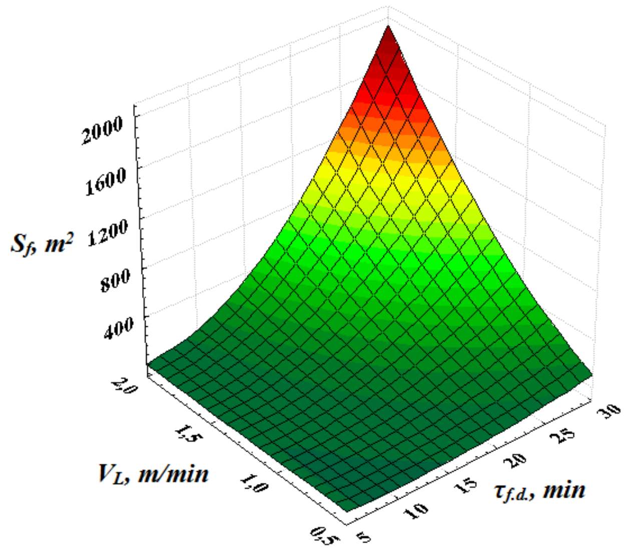

Fig. 2. Dependence of the area of angle (90°) fire S_f on $\tau_{f.d}$ and V_L

Analysis of dependency (7) and Fig. 2 shows that even a slight decrease in the $\tau_{f.d.}$ will allow reducing the S_f significantly and, accordingly, the amount of the due losses.

According to statistics, the key importance in dependency (1) is attached to the τ_{tt} – the duration of travel of the unit to the place of the call. The value of τ_{tt} depends on many factors. The first thing is the distance toward the place of the call. Also the τ_{tt} is affected by the quality of the road surface, the width of the lanes and curbs, the radii of turns, visibility, the height of the curb stone, etc. One should not reject the influence of intersections, pedestrian crossings and parked vehicles.

The speed of a fire extinguishing vehicle is also significantly affected by the intensity of traffic flows, which changes not only depending on the parameters of the road network, but also on the time of day. Unfortunately, the importance of the influence of the above-mentioned factors is often neglected. For example, according to the paper [18], for the calculations it is recommended to consider the average speed of a fire extinguishing vehicle at 45 km/h on wide streets with hard coverage and 25 km/h in tough areas.

Given the above-described, the authors, to design an algorithm of efficient management of fire rescue units' activities', based on data [19] and applying the software package STATISTICA, obtained dependencies allowing determination of the duration of the travel of a fire extinguishing vehicle to the place of the call and, as a consequence, the area of the fire (the example shows the case of V_L=1 m/min, angle, 90°) depending on the distance to the place of the call and the time of day :

$$\tau_{tt.} = -2{,}78 + 1{,}97L + 0{,}5364T - 0{,}0187T^2, min; \quad (8)$$

$$S_f = 80{,}0848 + 46{,}4554L + 18{,}6189T + 3{,}0465L^2 + \\ +0{,}0353LT - 0{,}656T^2, m^2, \quad (9)$$

where L is the distance to the place of the call, km; T is the time of day within 0–24 (from 0 to 8, 24 must be included in dependency (9)), hours.

Therefore, in order to optimize the values of $\tau_{f.d}$, τ_{loc} and τ_{liqv} let us consider the design of the algorithm of efficient management of fire rescue units' activities. In this case, the objective function will look

$$\tau_{f.d.} \to \min, \tag{10}$$

$$\tau_{tt} \to \min, \tag{11}$$

$$\tau_{loc} \to \min, \tag{12}$$

$$\tau_{liqv} \to \min. \tag{13}$$

Taking into account the return of fire extinguishing vehicle back to the base, it is advisable to consider its route in terms of the travel costs through a road network. In this case, the objective function will look

$$C \to \min, \tag{14}$$

where C is the cost of travel of the fire rescue unit, determined by the dependency [17]:

$$C_{I-J} = C_{var} l_{I-j} + \\ + C_{cons} \frac{l_{I-J}}{V_{I-J}} + \frac{0,38 + 1,6 \cdot 10^{-4} N_{I-J}}{365 N_{I-J}} C_{RA} \quad [\text{UAH}], \tag{15}$$

where C_{var} is the vehicle's variable costs, UAH/km; $l_{I\text{-}J}$ is the arc length I–J, km; C_{cons} is the vehicle's constant costs, UAH/year; $V_{I\text{-}J}$ is the vehicle average speed along the distance I–J, km/h; $N_{I\text{-}J}$ is the traffic intensity along the arc I–J, cars/24 hours; C_{RA} is an average loss from one road accident, UAH.

For efficient management of the fire rescue units' activities according to the criteria (10)–(14) based on dependencies (7)–(9), (15) an algorithm in the form of a simulation model (Fig. 3) was designed.

Based on Fig. 3, let us consider the step-by-step performance of the proposed algorithm – simulation model for efficient management of the fire rescue units' activities. In block 1 we enter incoming data that highlight the coordinates of the fire place and the whereabouts of a fire rescue unit. In the next block 2 we determine the number of possible routes A. For this purpose we may use electronic maps and cascading graph options for travel of vehicles [1] with marked transport nodes and arcs of road network. Block 3 defines values τ_{tt} for each of the proposed routes from the set A with the help of dependency (8). Then in block 4 we determine the lowest value of the parameter τ_{tt} by criterion (11) from the set received in block 3. Next, in block 5, the route of travel of a fire extinguishing vehicle towards the location of the call is marked on the map of a road network. After this, in block 6 we define the estimated area of fire S_f by the moment of arrival of a fire rescue unit by dependency (9). In block 7 the grade of fire is defined as well as the required quantity of forces and facilities for its elimination by the criteria (12), (13). To achieve this, a computer software program applies [14], which is described in the next section of this paper. Then in the simulation model we determine the optimal route of return back to the base by the criterion (14), using the dependency (15). Operations in blocks 8–11 are similar to the operations described for blocks 2–5.

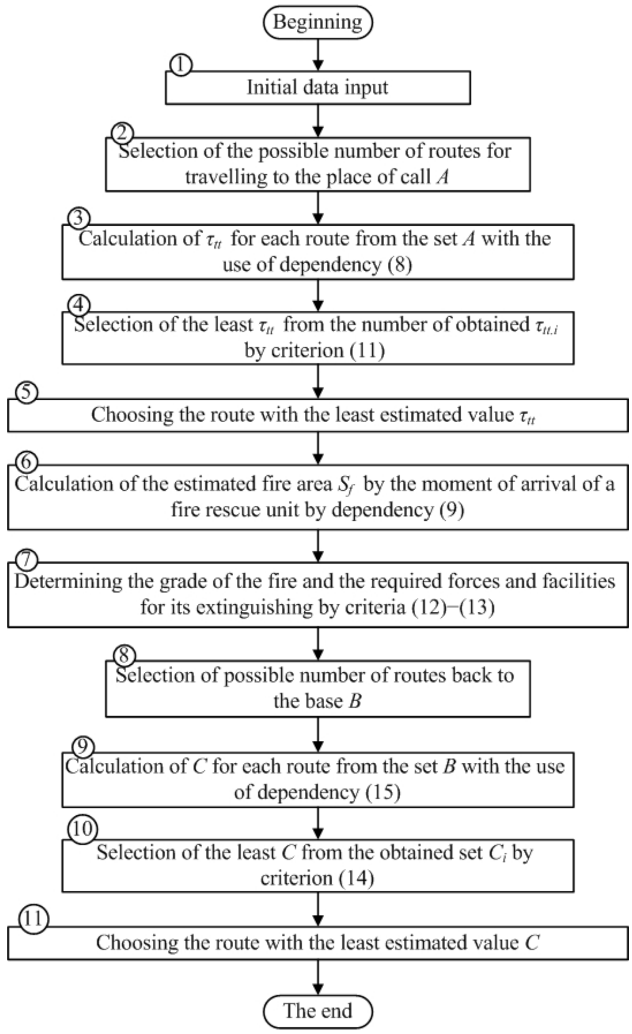

Fig. 3. Block diagram of an algorithm-simulation model for efficient management of the fire rescue units' activities by criteria (10)–(14)

6. Discussion of the results of research of influence of the drivers on the periods of fire and the designed optimization algorithm for efficient management of fire rescue units' activities

The obtained algorithm will allow the head of fire extinguishing significantly facilitate the calculation of the parameters of development and elimination of fire, as well as the optimal quantity of the forces and facilities for its elimination. The algorithm also provides the optimization of travel routes of a fire rescue unit to the place of the call and return to the base of the department. The travel route of a fire rescue unit, obtained by criterion (11), is optimal in the case of moving towards the fire, because in this case one of the determining factors is $\tau_{f.d}$, which directly depends on the τ_{tt}. And if a fire truck returns to the location of its department or moves on to provide services or fire safety (football match, a concert, etc.), then it is advisable to choose the route according to the criterion (14), because in this case the travel costs will be minimal.

The final stage of research is developing a computer software program based on the obtained algorithm of the efficient management of the fire rescue units' activities. It is worth noting that such a program was created on the basis of the algorithm [14] and integrated in the simulation model, which is considered in this paper. Fig. 4 displays general view of the desktop window for selecting capabilities to eliminate grade A fire at an industrial enterprise. Fig. 5 presents the desktop window of the same program for grade B fires.

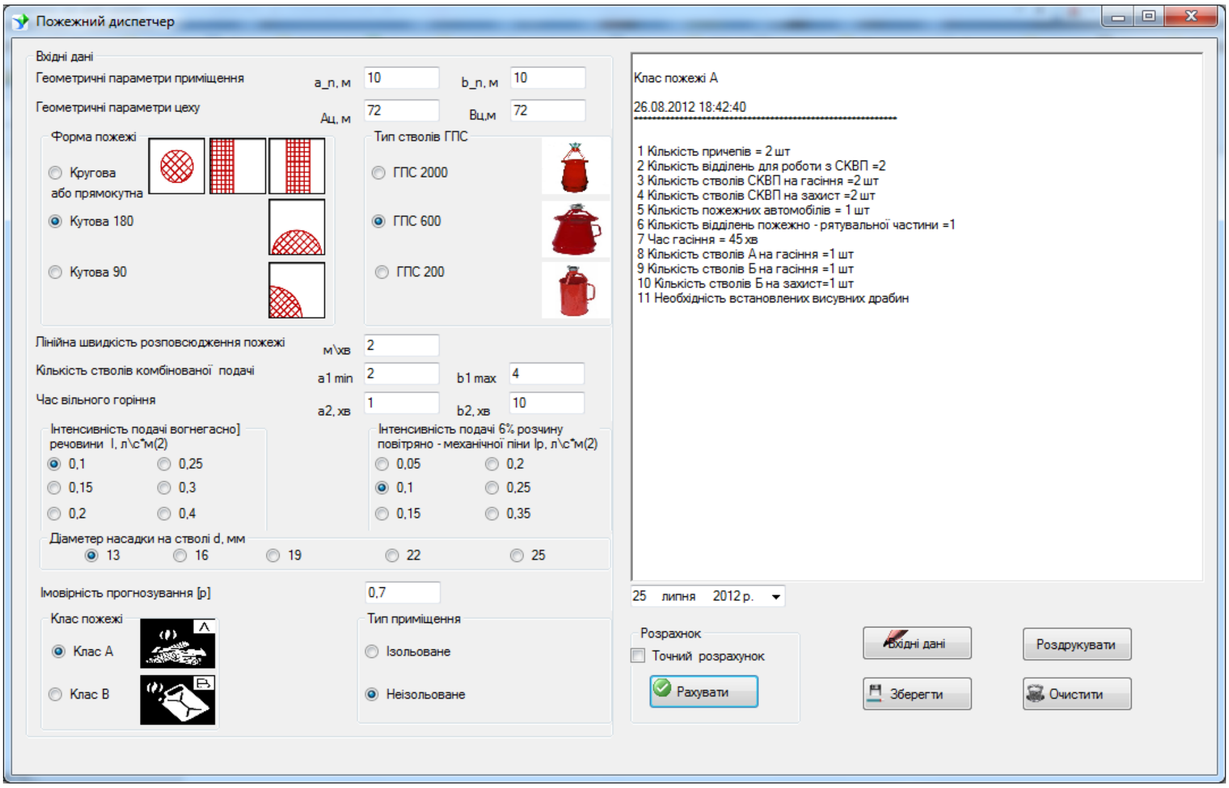

Fig. 4. General view of the desktop window of the software program for selecting capabilities to eliminate grade A fire at an industrial enterprise

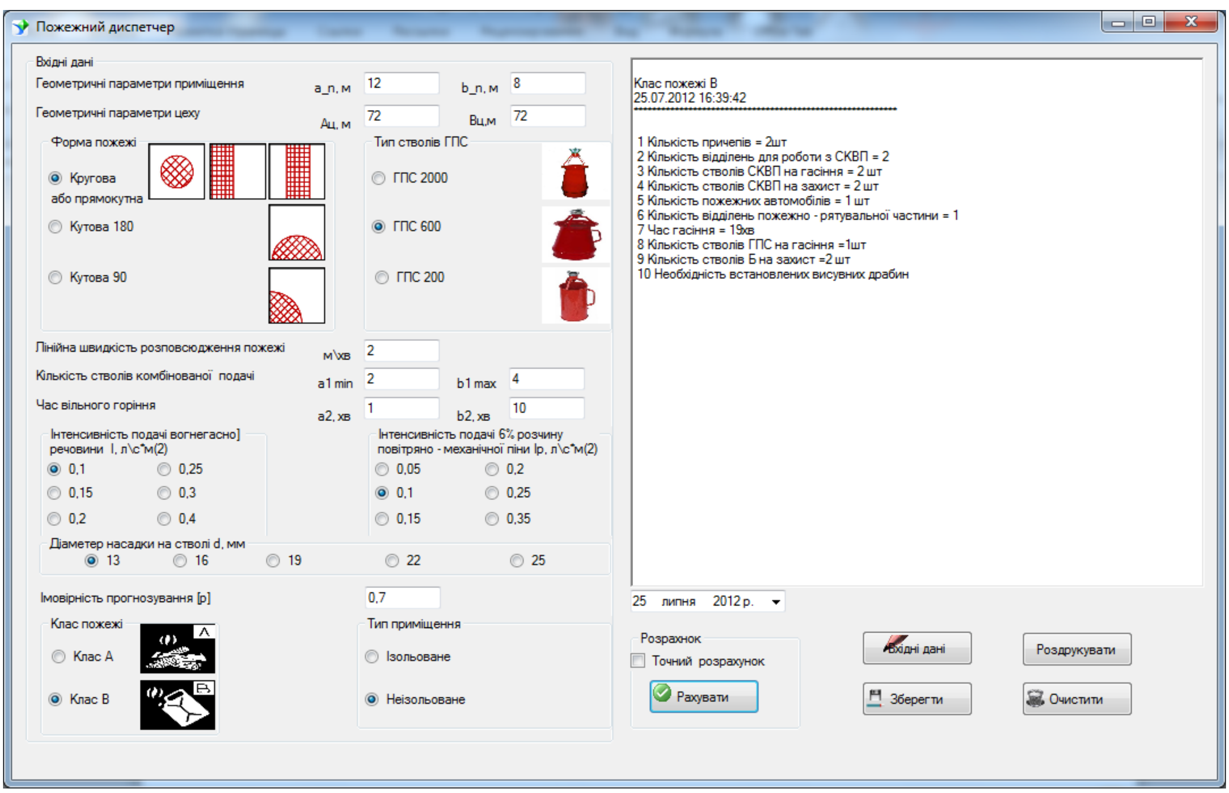

Fig. 5. General view of the desktop window of the software program for selecting capabilities to eliminate grade B fire at an industrial enterprise

Software program (Fig. 4, 5) for PC was written in the programming language C# for Windows XP and Windows 7 operating systems. As a result of the program's work for grades A and B fires, we receive the estimated quantity of forces and facilities for the elimination of a fire. It should also be noted that the obtained results can be corrected by the head of fire extinguishing during the elimination of the fire, based on the data attained in the course of exploration.

During testing on a PC with the processor Celeron (R) Dual-Core CPU T3500 @ 2.10 GHz 2.09 GHz and 3 GB of RAM, while performing the calculations with probability prediction [p]=0,5, the operation time comprised 2–3 s; with probability prediction [p]=0,7 – 6–8 s, and with probability prediction [p]=0,9–13–20 s. And the PC software programme took up no more than 13 Mb of the operational memory.

7. Conclusions

Based on the analysis of the process of development and elimination of fire, the need to assess the travel time of a fire extinguishing vehicle to the place of the call and the fire area as determining drivers of successful firefighting was substantiated. The dependency was received that allows calculating the value of a fire area depending on the duration of its free development and linear velocity of expanding. The analysis of this dependency shows that even a slight reduction in the duration of the free development of fire will significantly reduce the area of the fire and the amount of due losses. To design the algorithm of efficient management of the fire rescue units' activities using the software package STATISTICA, we obtained dependencies allowing setting the value of travel time of a fire extinguishing vehicle towards the place of the call and, consequently, the area of the fire (the example shows the case of V_L=1 m/min, angle, 90°) depending on the distance to the destination of the call and the time of day.

The necessity was substantiated and a block diagram of algorithm – simulation model of efficient management of the fire rescue units' activities was designed. The algorithm makes it possible to determine the optimal routes of fire rescue vehicles and to estimate the area of a fire by the proposed dependencies, as well as to choose the optimal technology for fire extinguishing. A computer program, developed on the basis of this algorithm, will allow the head of fire extinguishing to facilitate the calculation of the parameters of development and elimination of fire, as well as the optimal number of capabilities for its elimination. A software program to select the optimal technology of firefighting was also considered. The program for PC was written in the programming language C# for the Windows XP and Windows 7 operating systems. As a result of the program's work for grades A and B fires, the estimated quantity of forces and facilities for elimination of fire was obtained. It should also be noted that the obtained results can be corrected by the head of fire extinguishing during the elimination of the fire on the basis of the data obtained in the course of exploration. During testing on a PC with the processor Celeron (R) Dual-Core CPU T3500 @ 2.10 GHz 2.09 GHz and 3 GB of RAM, while performing the calculations with probability prediction [p]=0,5, the operation time comprised 2–3 s; with probability prediction [p]=0,7 – 6–8 s, and with probability prediction [p]=0,9–13–20 s. And the PC software program took up no more than 13 Mb of the operational memory.

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E-READINESS EVALUATION MODELLING FOR MONITORING THE NATIONAL E-GOVERNMENT PROGRAMME (BY THE EXAMPLE OF UKRAINE)

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Проаналізовано системи формування міжнародних індексів електронної зрілості державного управління. Виявлено специфіку динаміки реалізації програми «Електронна Україна» у рамках базових субіндексів міжнародних систем оцінювання е-врядування. Зазначено, що прогрес у поліпшенні показників індексу он-лайн сервісу потребує відповідного контенту управлінської зрілості системи врядування. Керуючись методологією програмного менеджменту, запропоновано багатокритеріальну систему оцінки змісту процесів моніторингу національної е-програми

Ключові слова: е-врядування, електронна готовність, он-лайн сервіс, стейкхолдери, менеджмент програм, зрілість управління

Проанализированы системы формирования международных индексов электронной зрелости государственного управления. Выявлена специфика динамики реализации программы «Электронная Украина» в рамках базовых субиндексов оценки э-управления. Отмечено, что для улучшения показателей индекса он-лайн сервиса требуется соответствующий контент управленческой зрелости системы. Руководствуясь методологией программного менеджмента, предложена многокритериальная система для формирования содержания процессов мониторинга национальной э-программы

Ключевые слова: э-управление, электронная готовность, он-лайн сервис, стейкхолдеры, менеджмент программ, зрелость управления

1. Introduction

Use of information and communications technologies (ICTs) is a necessary component of programmes and projects to increase public administration efficiency. ICTs can help improve the quality of public services, transparency of power and the level of trust to it among citizens as well as produce an overall positive effect on the competitiveness and welfare of nations. Special methods are developed and indices are calculated to assess the level of implementing the e-government tools that determine the rankings of the corresponding countries (including the Networked Readiness Index [1] and the UN E-Government Development Index [2, 3]). In spite of the rapid rate of globalization, there are significant differ-